# Study of Acid-Stained Concrete Flooring and its Effect on Compressive Strength of Concrete

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**Abstract:** Flooring in any building affects the interior to much extent. Flooring techniques normally being used in Asia and especially Pakistan are rigid. Normally used flooring types are marble flooring, ceramic tiles, mosaic flooring, wooden flooring, PVC sheeting, vinyl sheeting, etc. All of these floors once installed cannot be redesigned without destructing the previous material and installing from the start. Many other problems are associated with different flooring types. For example, ceramic tile design trend varies within a very short time and one cannot find the same design if needed for conserving partially damaged floor or to install the same design in an adjacent place that was left before. On the other hand, acid staining can be done multiple times on the same concrete surface without any destruction and comparatively low cost. This research introduced the usage of concrete as a decorative finish by applying acid staining. Acid stains are solutions of diluted hydrochloric acid with inorganic salts. An acid stain is applied to the set/hardened plain cement concrete floor surface. The application of acid stain corrodes the concrete surface a bit and the salt present in acid stain reacts chemically with the hydroxide of cement to form new compounds of different colors. Acid stains can be applied multiple times to redesign and recolor the surface at a low cost compared to other flooring techniques. Acid stain takes almost 6-8 hours to stain the surface. It is then neutralized with ammonia/some other alkaline solution to stop the corrosion effect of acid. The floor can then be washed. The sealer is then applied to the dry surface of the stained floor to impart a glorious look and make the color permanent for a longer time. Departmental laboratory floor and concrete samples are used in experimentation. Some tones of brown and green colors are achieved. The effect of this application on the compressive strength of the concrete floor is also tested.

**Keywords:** HCl Hydrochloric Acid, $H_2SO_4$ Sulfuric Acid, Aesthetics, Acid Stain, Compressive Strength, Flooring

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## 1. Introduction:

Flooring is one of the major aspects of any building's interior design that can enhance the aesthetics and attraction of the user [1]. Aesthetics and strength are major aspects of the floor design. Different usage of floor specifies the priorities of design of the floor e.g., the floor of the area that is subjected to heavy loading needs to be strong first even if its aesthetics are not as good, on the other hand, the floor of a living room of a residential building must be attractive in looks along with strength which is quite low as compared to the one in the last example. The glossy finish of the floor looks good but cannot be used in an area of water usage [2]. Floors are of different types like hardwood flooring, vinyl flooring, vinyl sheet flooring, tile flooring, mosaic flooring, laminate, natural stone/marble flooring, etc. [3]. Almost all these types of floors need some proper base to be constructed before we apply the finishing on the top of it. This base floor is usually made of Plain cement concrete (P.C.C). This provides a rigid base for the finish and also requires a slope for drainage purposes. Finish tile marble or any other material sheet is then bonded to the PCC using different bonding materials depending on the type of finish floor. These finishes are bonded rigidly to the base floor and cannot be removed until damaged. Every floor type has a specific life after which it needs maintenance or repair or a complete change. Maintenance and repair do not increase the strength of existing flooring, neither the design nor the finish of the floor can be changed. A complete change of floor finishing material will be required to have better strength and a new finish but will need more time and cost. For an office building or any other area under usage, it is quite difficult to abandon the area for a week or fortnight [4]. So, a floor type that has good strength, a better finish, and which do not need more maintenance and repair compared

to other floors is needed. A saturated solution of diluted hydrochloric acid with some inorganic salt is called an acid stain. Acid staining the concrete floors gives it a new aesthetic look without losing the strength of the floor significantly. Multiple colors and patterns can be achieved by using different acid stains [5].

## 2. Literature Review

Applying acid and then neutralizing it with ammonia or some other alkaline solution can affect the internal and external performance of the concrete. Change in pH has experimentally proved to cause some serious inadequacies and limitations of performance with time. Moreover, chemicals like chlorine also affect the pH in case of moisture presence [6]. This is managed by using a much-diluted solution of acid that is enough to bite the cream of hardened concrete and expose the inner surface with which the salt/s present in the acid stain can react and impart color. Acid stain once applied is neutralized by applying the base within 6-8 hours, so the change in pH is not significant [7]. Acid dilution does not allow the stain to penetrate more than 4-5 mm in the concrete surface. Salts that contain chlorine like iron chloride, copper chloride can destroy concrete as the chloride ingress into the concrete strata and this diffusion is also time-dependent. Chloride transport is also affected by atmospheric conditions and the presence of moisture [8].

Corrosion of up to 20% in the reinforced or plain concrete causes the loading capacity destruction of up to 10% [9]. This research revealed that the acid staining does not cause this much corrosion because of limited time application because the overall load capacity reduction comes to be less than the above-mentioned. Concrete floors are usually washed for cleaning purposes and then mopped to get dry regularly. Concrete areas exposed to regular drying-wetting cycles support the chloride penetration to the concrete [10]. It is not possible for any building to be used to avoid washing or cleaning the floor without water usage. This is managed by sealing the concrete surface after acid staining. The sealer layer not only gives a glossy attractive look to the floor by enhancing the colors of stains but also makes it water-repellent due to oil-based formula [11].

Alkalinity with the presence of moisture and lead material produces red, yellow, and orange stains in marble and other materials that are quite impossible to remove. This phenomenon was observed in stained concrete floors before it was applied with sealer.

An acid-stained Pool deck floor

Designed with Acid-stained Concrete floor

**Figure 1: Acid-Stained Concrete Floors**

## 3. Materials

This research emphasizes on a new floor finishing technique for the concrete floor, so the major materials are the components of the concrete and acid stains. concrete flooring is made of plain cement concrete whose components are ordinary Portland cement (OPC), coarse and fine aggregates, and water for mixing the components in a good blend. Acid stains as clear from the name are the acid-based solutions that are used to impart good graphics or finish to the floor. Inorganic research by Carol A. Grissom in 2018 [12]. This necessitates the washing of acid-- salts are added to the diluted acid solution to make different acid stains. The major materials used are as follows:

### *3.1 Ferric Sulfate or Iron Sulfate ($FeSO_4.7H_2O$)*

Iron Sulfate (also known as Copperas) is usually formed in two forms which are ferric Sulfate Hepta-hydrate and ferrous Sulfate monohydrate. Later one is a purer form of the compound. This is usually obtained as a byproduct in the manufacturing process of titanium oxide. Ferric Sulfate is a light green color compound and is water soluble and acidic in nature [13].

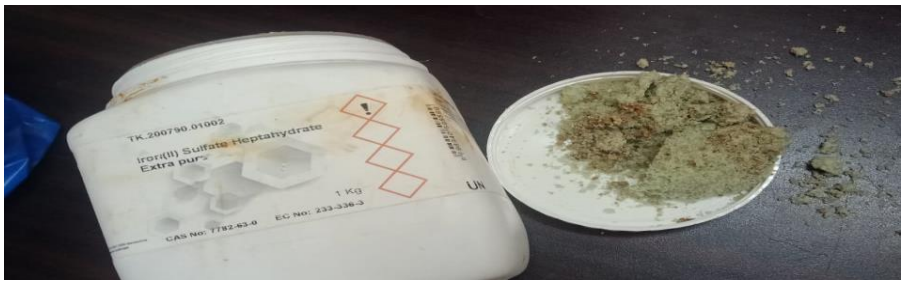


**Figure 2: Laboratory packing of pure ferric Sulfate Hepta-Hydrate** [13]

As the salt is water soluble, it absorbs moisture from the surroundings due to which its color changes to brownish particles. Ferric Sulfate is a source of iron metal in the manufacturing of different industrial products. This salt is being used in the manufacturing of cement to reduce chromium levels in the cement [14]. Animal feeds production procedure also includes this salt for the supply of iron requirement to the feed. Ferric Sulfate is also used to improve coagulation and removal of some unwanted compounds in the water treatment plants. It is also used in the mining process and biogas tre

### *3.2. Iron or Ferric chloride ($FeCl_3$)*

Iron chloride is also found in two forms that is being used as a color generator/imparter to the concrete surface. are ferric chloride ($FeCl_3$) and ferrous Chloride ($FeCl_2$). The one in the picture below is the laboratory chemical Ferric Chloride with a misprint of the formula $FeCl_2$. Ferrous chloride is white color crystal form compound while ferric chloride is normally not found in pure form. Pure ferric chloride crystals change color when viewe when mixed with water or acid[15].

**Figure 3: Laboratory packing of ferric chloride**

Industrially this material is being used as water treatment for drinking process and sewage treatment processes due to its ability to react with the hydroxide ion to produce iron hydroxide. Iron hydroxide removes the suspended particles from the water. It is also used as a catalyst in some hydrocarbons reaction with chlorine. It has the ability to precipitate out the phosphate content, for which it is sometimes used in the water treatment process. It is a toxic compound and causes burns to the aluminum metal if came in contact. Ferric chloride is being used in this research work as a stain producer or color imparter to the set concrete surface bitten by acid.

### *3.3.Copper Chloride ($CuCl_2$)*

Copper chloride occurs naturally as well as it is synthesized by chlorinating the copper

metal. In pure form, this solid compound is light brown but is very rarely found in pure form. The normally available form of copper chloride is bi-hydrate means that attached to it are two water molecules [16]. This compound is light green and solid in the form at room temperature. A laboratory material picture is as below.


**Figure 4: Laboratory packing of copper chloride (CuCl2.2H2O)**

It is used as a catalyst in the Wacker process to convert the palladium back to palladium chloride by re-oxidizing. This compound is also used to produce chlorine from hydrochloric acid. Due to its effect on the chlorination of hydrocarbons, it is also used in the synthesis of different organic compounds [17]. Copper chloride salt is used as a stain or color producer in the diluted acid solution in this research study.

### *3.4. Copper Sulfate ($CuSO_4$)*

Copper Sulfate also known as bluestone is extremely poisonous material. Swallowed in minor amounts can cause death. It is composed of copper, sulfur, and oxygen. It is blue in color and odorless. It is formed by the reaction of hot Sulfuric acid with copper metal. It is used as an Antifungal agent in water bodies and for skin antiseptic for a long time.


**Figure 5: Laboratory packing of Copper Sulfate (CuSO4)** [18]

Medical uses of copper Sulfate include treatment for warts, toothache relief, fungal treatment of Athletes' feet and toenails, etc. Its usage can lead to anemia. It is an irritating compound so special care should be taken while using. Safety elements if come in contact with and are supposed to be used in the future should be rinsed to clean any compound traces [18]. Usage of this salt in this study is to generate color stains on the concrete surface.

### *3.5. Hydrochloric Acid (HCl)*

Hydrochloric acid also known as Muriatic acid is a highly corrosive liquid. It can cause severe burns to the skin, eyes, or other parts of the human body. Special precautions should be taken to use them. Fumes develop when the acid is diluted or applied over some surface.

**Figure 6: Hydrochloric Acid purchased from Local Market**

Inhalation of those fumes causes nasal irritation, so precautionary measures should be taken to avoid such conditions. Gastric juice in the human body is hydrochloric acid that helps digestion. Hydrochloric acid is extensively used in rubber industries, textiles, dye-making processes, electroplating, etc. It is also used in fertilizer manufacturing and chloride production. Long-time exposure or usage of hydrochloric acid can lead to corrosion of internal body parts like the stomach, membranes, esophagus, etc.

if exposure is through inhalation. However, the EPA (Environmental Protection Agency USA) has not nominated this solution as carcinogenic. Diluted hydrochloric acid in this research study is used as a solvent for the acid stain solutions for making out color patterns on the concrete surface. The literature of this study also defines this acid as more helpful in producing successful acid stains compared to other acids for the same purpose.

### *3.6.Sulfuric Acid ($H_2SO_4$)*

burns, its exothermic reaction can cause heat burns as well. It is usually used in drain Sulfuric or Sulfuric Acid is a powerful solution that can cause severe damage if came in contact with the human body even at moderate concentrations. It is hygroscopic means it absorbs water from the surroundings and the reaction is highly exothermic. Along with chemical cleaners. It is used as an electrolyte in lead accumulators or lead-acid batteries.

**Figure 7: Sulfuric Acid H2**


Sulfuric acid is also used in fertilizer manufacturing, oil refining process, water treatment, etc. This solution is of such importance that its manufacturing quantity is a parameter to measure the strength of some area's industrial strength. Its regular users suffer teeth erosion with time. Sulfuric acid diluted solution is used as a solvent for salts that will produce color in the concrete surface by reacting with the cement components after the action of acid on the surface.

### *3.7.Ammonium hydroxide*

Ammonium hydroxide or ammonia solution is an aqueous solution of ammonia gas. It is an easily available solution at pharmacies and science stores. It is basic in nature and is used for drugs used for minimizing acidity, baking process, etc. Multiple purposes. It is used in cleaners for household jobs, water disinfection or treatment processes, as a component in food

Ammonia solution is also used in woodwork for wood fuming to enhance the wood pattern by darkening the wood's tone. This process is best suited to white oak wood. Cattle straw is also treated with an ammonia solution. It makes it more edible for the cattle [19]. Ammonia solution usage in this research study is to neutralize the acidic effect of the acid stains that are applied to the concrete surface to change its appearance. Negating the acidic effect by the usage of this base stops the further corrosion of the concrete due to acid.


## 4. Research Methodology

**Preparing Acid Solutions**

**Applying Ferric Chloride Acid Solution on concrete cubes**

**Applying Copper Chloride Acid Solution on concrete cubes**

**Applying Ferric Sulfate acid stain to cube sample**

**Application of different stain solutions to concrete cube and slab samples**

**Applying iron sulfate and copper sulfate acid stain to the laboratory floor at BZU (Bahauddin Zakariya University) Multan**

**Applying iron sulfate, copper sulfate, copper chloride, and sodium sulfate acid stain solutions to the laboratory floor at Building & Architectural Engineering Department BZU Multan.**

**Acid-stained area washed after ammonia solution application**

**Figure 9: Research Methodology**

### *4.1. Neutralizing, washing, and sealing*

The acid-stained surface is allowed to dry and penetrate the concrete surface. Penetration of acid stain causes the reaction of salt with the hydroxide of cement and imparts color. Stains normally take 7-8 hours to impart the maximum color to the surface. The stained surface is then neutralized by applying the ammonia solution to the surface and is left for some time to neutralize the concrete surface. This is then washed and dried. The washed acid-stained surface is then polished or sealed using some epoxy resins or marble polish.

### *4.2. Cost Estimation & Feasibility*

For the sake of comparison, a 100 square meter area is taken and the costs of different flooring techniques are quantified. All the cost analysis of different types of flooring is based on just the finishing cost excluding the costs till the base PCC floor.

### *4.3.Rough Cost Estimate for different types of flooring*

#### *Ceramic tile installation cost*

Different costs for installing a ceramic tile floor of general type are as follows:

Wet cement mortar required for 100 $m^2$ area = 100 $m^2$ x 0.05 m (thickness) = 5 $m^3$

Dry volume of Cement mortar required = 1.25 times of wet volume = 6.25

If we use 1:4 cement sand mortar then

Quantity of cement required = 6.25x 1/5 = 1.25 $m^3$

**Quantity of sand required = 6.25 x 4/5 = 5 $m^3$ or 176.5 $ft^3$**

1 cement bag = 1.25 $ft^3$ or 0.035 $m^3$

**No. of bags of cement required = 1.25/0.035 = 35.71 means 32 bags**

Installation cost or Labor per Square meter = 370 /- PKR or 2.64 USD approx.

Ceramic Tile per square meter = 1000/- PKR or 7.14 USD approx.

**Table 1: Rough Cost Estimate for Ceramic Tile Floor Installation**

| Description | Quantity | Unit Rate (USD) | Cost (USD) |
|---|---|---|---|
| Tile | 100 $m^2$ | 7.14/$m^2$ | 714 |
| Cement | 32 bags | 4.2 / bag | 134.4 |
| Sand | 5 $m^3$ | 4.285 /$m^3$ | 21.43 |
| Filling | 20 boxes | 1.5 / box | 30 |
| Labor | 100 m3 | 2.64 /m3 | 264 |
| | TOTAL COST: | | 1163.83 |

### *4.4. Marble Floor Installation cost*

Different costs for installing a marble floor of general type are as follows:

Wet cement mortar required for 100 $m^2$ area = 100 $m^2$ x 0.05 m (thickness) = 5 $m^3$

Dry volume of Cement mortar required = 1.25 times of wet volume = 6.25

If we use 1:4 cement sand mortar then Quantity of cement required = 6.25x 1/5 = 1.25 $m^3$

Quantity of sand required = 6.25 x 4/5 = 5 $m^3$ or 176.5 $ft^3$

1 cement bag = 1.25 $ft^3$ or 0.035 $m^3$

No. of bags of cement required = 1.25/0.035 = 35.71 means 32 bags

Installation cost or Labor per Square meter = 300/- or 2.14 USD

Marble per square meter = 3.92USD or 550/-PKR

Grinding & Polishing cost = 1 dollar or 140/-PKR per square meter

**Table 2: Cost Estimate for Marble Floor Installation**

| Description | Quantity | Unit Rate (USD) | Cost (USD) |
|---|---|---|---|
| Marble | 100 $m^2$ | 3.92 / $m^2$ | 392 |
| Cement | 32 bags | 4.2 / bag | 134.4 |
| Sand | 5 $m^3$ | 4.285 / $m^3$ | 21.43 |
| Filling | 20 boxes | 1.5 / box | 30 |
| Labor | 100 $m^3$ | 2.14 / $m^3$ | 214 |
| Grinding & Polishing | 100 $m^2$ | 1 / $m^2$ | 100 |
| | TOTAL COST: | | 891.83 |

### *4.5.Acid-Stained Floor Installation Cost*

Different costs for installing acid-stained floors are as follows:

Salt quantity required = 10 KG's Approx.

Acid quantity required = 5 liters approx.

Polishing / sealing cost per square meter = 200/- PKR or 1.54 US

**Table 3: Rough Cost estimate for Acid staining the concrete floor**

| Description | Quantity | Unit Rate (USD) | Cost (USD) |
|---|---|---|---|
| Salts | 10 kg | 16 / kg | 160 |
| Acid | 5 liters | 0.5 / liter | 2.5 |
| Ammonia (Neutralizer) | 10 liters | 10 / liter or $dm^3$ | 100 |
| Sealer / Polishing | 15 liters | 4 / liter | 60 |
| | TOTAL COST: | | 322.5 |

A comparison of acid-stained concrete floors with two of the above-explained types of floors that are ceramic tiling and marble flooring shows that acid-stained flooring has a comparatively lesser cost and needs less time and technical staff for the installation.

## 5. Feasibility

Floor technique feasibility is not based on the costs of its installation only, its technical ease of installation, and the availability of materials and staff for installation if one does not dare to do this personally. Salts that have been used for making stains in this study are readily available at science stores locally and one can make the stains by first diluting the acid and then simply mixing the salt/s to it till the saturation or required amount to achieve a lighter tone. Moreover, the acid-stained floor can be easily redesigned if the color or design does not attract after the installation because the cost is almost one-third compared to marble flooring and one-fourth compared with ceramic tile flooring. Therefore, it is economically and technically feasible to design the floors in any custom design and color.

## 6. Results & Recommendations

Different salts of an inorganic nature are tested for the production of an aesthetically good-looking finish without compromising the compressive strength of the concrete floor. Two different acids are used to formulate different acid stains with different dilutions to check the corrosion effect of acid on the concrete surface. Different concrete samples are applied with different acid stains in multiple layers to achieve the required tone. Grinding and polishing of the samples is done using the polishing

machine to give gloss to the surface and seal the surface against the weathering effect, routine cleaning, and washing process. due to limited color range production with salts, some water-soluble colors are also added to the stains for customized tones production. Any good stain that gives a good finish to the concrete surface is not acceptable if it damages the surface to the extent that results in the floor surface failure. Samples are tested for compressive strength after 28 days to check the reduction in compressive strength due to acid application, if any.

### *6.1. Results*

Results obtained with different stain compositions are tabulated in Table 4 below:

**Table 4: Color Results Obtained with different acid stains**

| PCC Sample Description | PCC ratio | Stain Composition (All stain samples are saturated) | Color tone achieved | Compressive e strength in psi | Percentage reduction in Compression ve strength |
|---|---|---|---|---|---|
| Cube #1 | 1:2:4 | No Stain (Reference sample) | No color change | 2513.92 | Reference |
| Cube # 2 | 1:2:4 | 12%HCL+$FeSO_4$ (1 Layer) 12%HCL+$FeCl_3$ (1 Layer) | Dark Brown | 2191.88 | 12.88% |
| Cube # 3 | 1:2:4 | 12%HCL+ $FeSO_4$ (2 Layers) | Brown | 2160.67 | 14.05% |
| Cube # 4 | 1:2:4 | 10%$H_2SO_4$+$FeSO_4$ (1 Layer) | Light Brown | 2048.27 | 18.5% |
| Cube # 5 | 1:2:4 | 10%HCL+ $FeCl_3$ (2 Layers) | Dark Brown | 2360.51 | 6.11% |
| Cube # 6 | 1:2:4 | 10%HCL+ $CuCl_2$ (2 Layers) | Light Green | 2302.43 | 8.42% |
| Cube # 7 | 1:1.5:3 | No Stain (Reference sample) | No Color | 2818.24 | Reference |
| Cube # 8 | 1:1.5:3 | 9%HCL+$FeSO_4$ (3 Layers) | Yellowish brown | 2675.86 | 5.06% |
| Cube # 9 | 1:1.5:3 | 10%HCL+$CuSO_4$ (2 Layers) | Light green | 2498.6 | 11.35% |

ASTM C42/C42M is the standard method for testing the slab core samples and concrete beams core samples. This methodof testing provides procedures for testing in-place concrete about compressive strength, tensile strength, and flexural strength.

**Table 5: Color Results Obtained with different acid stains**

| PCC Sample Description | PCC ratio | Stain Composition | Color tone achieved | Compressive strength | Percentage reduction in Compressive strength |
|---|---|---|---|---|---|
| Slab # 1 | 1:2:4 | Plain PCC sample | No Color | 2135.23 | Reference |
| Slab # 2 | 1:2:4 | 12%HCL+$FeSO_4$ (3 Layers) | Brown | 2102.36 | 1.5% |
| Slab # 3 | 1:2:4 | 9%HCL+ $FeSO_4$ (2 Layers) | Light Brown | 2067 | 3.2% |
| Slab # 4 | 1:2:4 | 10%HCL+ $CuCl_2$ (2 Layers) | Light Green | 1974.89 | 7.51% |
| Slab # 5 | 1:2:4 | 10%HCL+ $FeCl_3$ (2 Layers) | Dark Brown | 2091.98 | 2.03% |
| Slab # 6 | 1:2:4 | 10%$H_2SO_4$ +$FeCl_3$ (2 Layers) | Dark Brown | 1806.29 | 15.41% |

Loads measured by the compression machine are divided by the respective areas of samples and results are represented in cubes and slabs graphical form for comparison

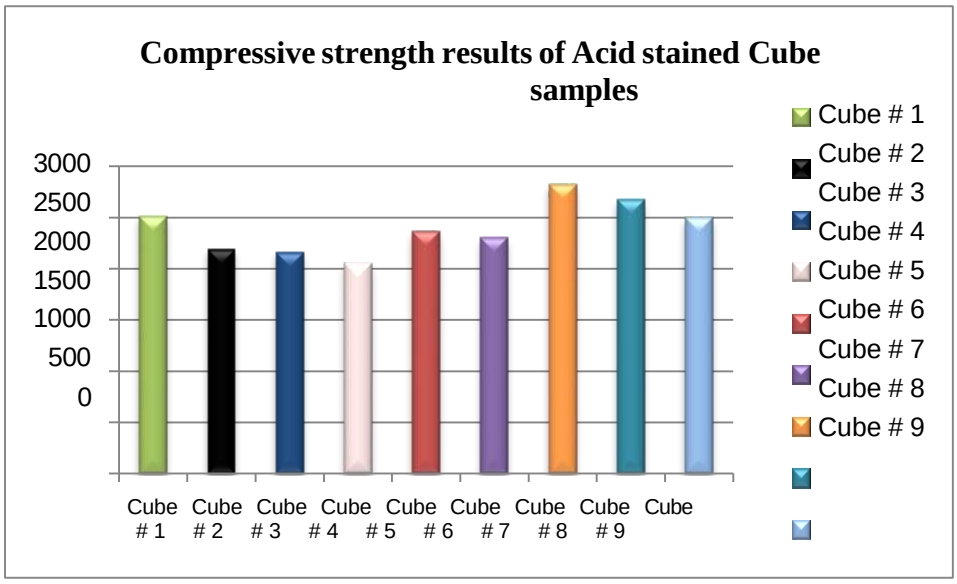


**Figure 10: Compressive strength of different cube samples**

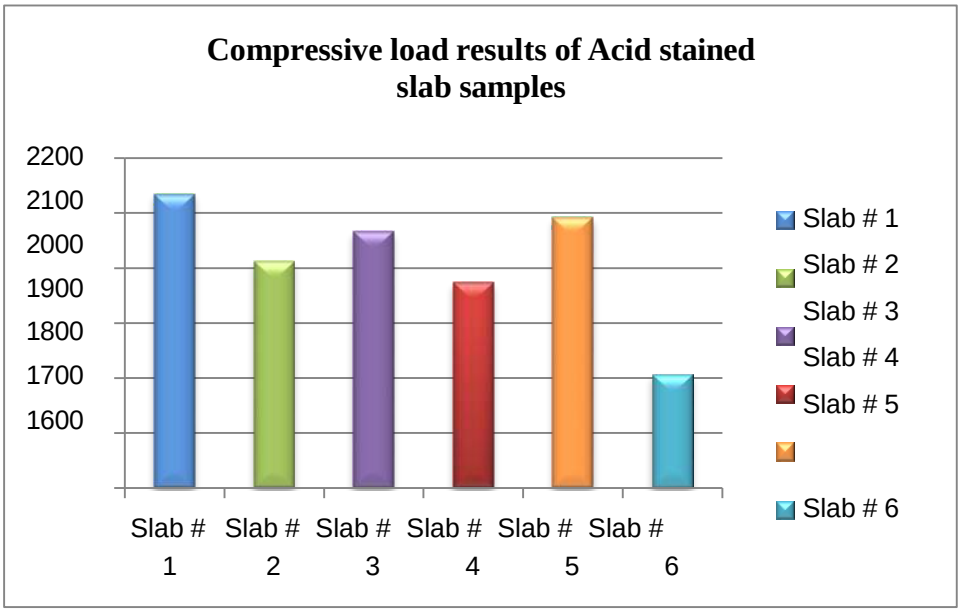


**Figure 11: Compressive strength of different Slab samples**

The compressive strength of the concrete samples is not much affected by the acid staining. Experiments show that less than 10.92% average reduction is observed in compressive strength testing of cube samples. Different tones of brown and green are obtained by the acid stains of an upper-given composition. Acid stains are very poisonous and corrosive to the skin as well. Mixing the ingredients to make stains is a risky job, so proper protection should be used. Make sure not to inhale fumes of any ingredient. Metallic salts are real poison and corrosive to the skin as well. An excessive amount of acid stain not only darkens the tone but also corrode the cream of the concrete floor surface. Mixing acid with water requires attention. Always add water to the acid because pouring acid in water may cause splash which is harmful.

**Conclusions**

This research concluded some formulations of simple-to-make acid stains and their application to achieve different color tones and patterns of floor design. Hydrochloric Acid resulted as a solvent resulted in good acid stain solutions compared to Sulfuric acid as the damage of sulfuric acid-based stains is more compared to the stains containing Hydrochloric acid. Following are the conclusions based on the experimental work of this research: It is concluded by the compressive strength test results of samples that the stains containing sulfuric acid as solvent resulted in more surface damage which resulted in more reduction of compressive strength while acid stains made with diluted hydrochloric acid resulted in lesser damage to the concrete surface.

A 6% average reduction in compressive strength is observed due to acid stain application in slab samples and up to

- Any stain made with any acid that is more than 20% in concentration resulted in severe damage to the concrete surface.
- Acid stains penetrate to the concrete surface up to 5 mm in depth.
- Salts of sodium mostly produce different tones of brown color when mixed with diluted hydrochloric acid.
- Copper-based salts produce very light shades of blue and green when mixed with hydrochloric acid. Sometimes, the tone achieved is too light to be detected because it resembles the green tone of concrete.
- Acid stains made with acids diluted up to 85-90% have a minor effect on

the compressive strength of the concrete floor. Reduction in average compressive strength due to acid staining is not more than 11% in cube samples and 6% in slab samples.

- The maximum reduction in compressive strength reduction out of all the samples is 18.5% and a minimum of 1.5% is observed in a test.
- Acid stains that produce very light colors can be added with some artificial colors which enhances the color density and hence the aesthetics.
- Adding different colors to the prepared acid stains also gives a variety of colors in which the floor can be stained.
- Sodium chloride (salt we normally use in food) is also tested to make a stain but it results in no color or pattern. Very light whitish stains appeared after application but vanished or we can say got washed on a water wipe.

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